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(Review Article)

Innovative hive intelligence: Stingless bee products and machine learning advancements in agriculture and medicine: A review

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Abstract

This literature review aims to explore the many applications of stingless bee products and advancements in machine learning related to stingless bees. The review includes research conducted from 2019 to 2023, with a primary focus on two key topics: the application of bee products and machine learning advancements. The review examines the various applications of stingless bee products, such as honey and bee bread, highlighting their potential in areas like medicine and anti-cancer treatments. Additionally, it examines modern machine learning advancements, including IoT systems and neural networks. The review adopts a hybrid approach, utilizing a systematic method to gather research on both stingless bee products and machine learning advancements. A total of 65 studies contributed to this research, revealing that a majority were conducted in Asia, with the genus of stingless bee Meliponini serving as the primary subject. Findings from these studies offer valuable insights for researchers, policymakers, and stakeholders interested in the sustainable utilization of stingless bee products and the integration of machine learning technologies in this domain.

Keywords: Stingless Bee; Machine Learning; Bee products; IoT; Review

1. Introduction

1.1. Health and Nutritional Benefits of Bee Products

Stingless bees are captivating contributors to biodiversity and human health in tropical and subtropical ecosystems. Composing over 500 known species, with approximately 40 demonstrating significant potential as honey producers [1], these bees represent about 70% of all eusocial bee species and exhibit a remarkable diversity in morphologies, behaviors, and life histories [2]. Within their nests, a rich array of microbiota, including bacteria, yeasts, filamentous fungi, and viruses, engages in complex relationships with the bees. This diverse microbial community serves multiple purposes—acting as symbiotic partners, a nutritional source for the bees, and producers of biomolecules that enhance the transformative properties of bee products like honey and bee bread [1]. As global awareness of the challenges facing bees increases, the medicinal applications of stingless bee honey and cerumen have gained prominence. Notably, stingless bees exhibit resilience against diseases compared to honeybees, making them promising sources of biologically active compounds. From Nepali communities in India to Abayanda pygmies in Uganda and various regions in Argentina, Bolivia, Guatemala, Mexico, and Venezuela, these unique bee products are employed for diverse health issues. Ongoing research indicates the therapeutic potential of stingless bee products in wound healing, diabetes, eye diseases, hypertension, fertility issues, cancer, microbial infections, and dysregulation [3,4]. Despite these promising aspects, further comprehensive studies are imperative to unlock the full therapeutic potential and unique characteristics of stingless bee products, continuing the exploration of these extraordinary contributors to biodiversity and human health [4].

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1.2. Potential Integration of Machine Learning in Beekeeping

In 2006, Colony Collapse Disorder led to significant losses in numerous stingless bee colonies and other bee species, emphasizing the urgent need for innovative solutions. Researchers have delved into optimizing stingless beehive conditions by harnessing the power of the Internet of Things (IoT) and machine learning. The exploration involves examining heterogeneous IoT data acquired from beehives and implementing machine learning techniques to uncover new relationships between hive processes and environmental characteristics. By focusing on variables like temperature, humidity, atmospheric pressure, and CO2, these efforts aim to mitigate the challenges posed by Colony Collapse Disorder [5]. Additionally, the pursuit of more accurate forecast models becomes crucial in understanding regular bee behavior and anticipating adverse situations. This not only aids in better bee management but also enhances their utilization as essential pollinators. One such investigation employs Recurrent Neural Networks to forecast bees' activity levels, incorporating previous activity values and environmental data such as temperature, solar irradiance, and barometric pressure [6]. In a research done by Anuar et al., (2022)[7], they proposed a forecast model that considers seven input vectors, including hive weight, inside and outside temperatures, humidity levels, dewpoint, and bee count, recognizing the multifaceted factors influencing a healthy bee colony. These are just some of the many approaches, found in this review, in order to implement modern technology in beekeeping. In this review paper, we attempt to analyze the health benefits of stingless bee products and current advancement in machine learning in agriculture and medicine.

2. Methodology

This review utilized a hybrid approach, employing a systematic method to gather research on stingless bee products and machine learning advancements in accordance with the guidelines outlined by Munn et al., Peters et al., and Zulhendri et al. [8–10]. The review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), incorporating the four-phase flow diagram suggested [11,12]. The guiding phrase of "Stingless Bee Products and Machine Learning Advancements" was applied in this review. JLMR and JLS, the two independent reviewers of this study, carried out the searches until December 2023. Thorough searches were done on databases such as Scopus, IEEE Xplore, Google Scholar, ScienceDirect, SpringerLink, and ResearchGate. Table 1 presents the search approach along with the terms incorporated in the exploration. Google Scholar employed constrained keyword searches to enhance the findings. Subsequently, the outcomes were categorized according to the first author, year published, title, focus, and continent (Asia, Africa, Australia, and America) corresponding to the origin country of stingless bee products and machine learning advances in agriculture and medicine in the conducted studies. Species of stingless bees used in these studies were also collected as well as a brief summary of the studies' findings. All studies detailing the advancements of studies in biological activities, chemical profiling, and machine learning on stingless bee products were included in this analysis. Researchers specifically excluded studies that did not provide information on the stingless bee products and machine learning advances in agriculture and medicine. Figure 1 outlines the screening process for the selected studies.

A comprehensive narrative review approach was employed, utilizing general keyword searches as "stingless bee products", "machine learning", "medicinal uses", "antibacterial activity", and "neural networks" across Scopus, IEEE Xplore, Google Scholar, ScienceDirect, SpringerLink, and ResearchGate.

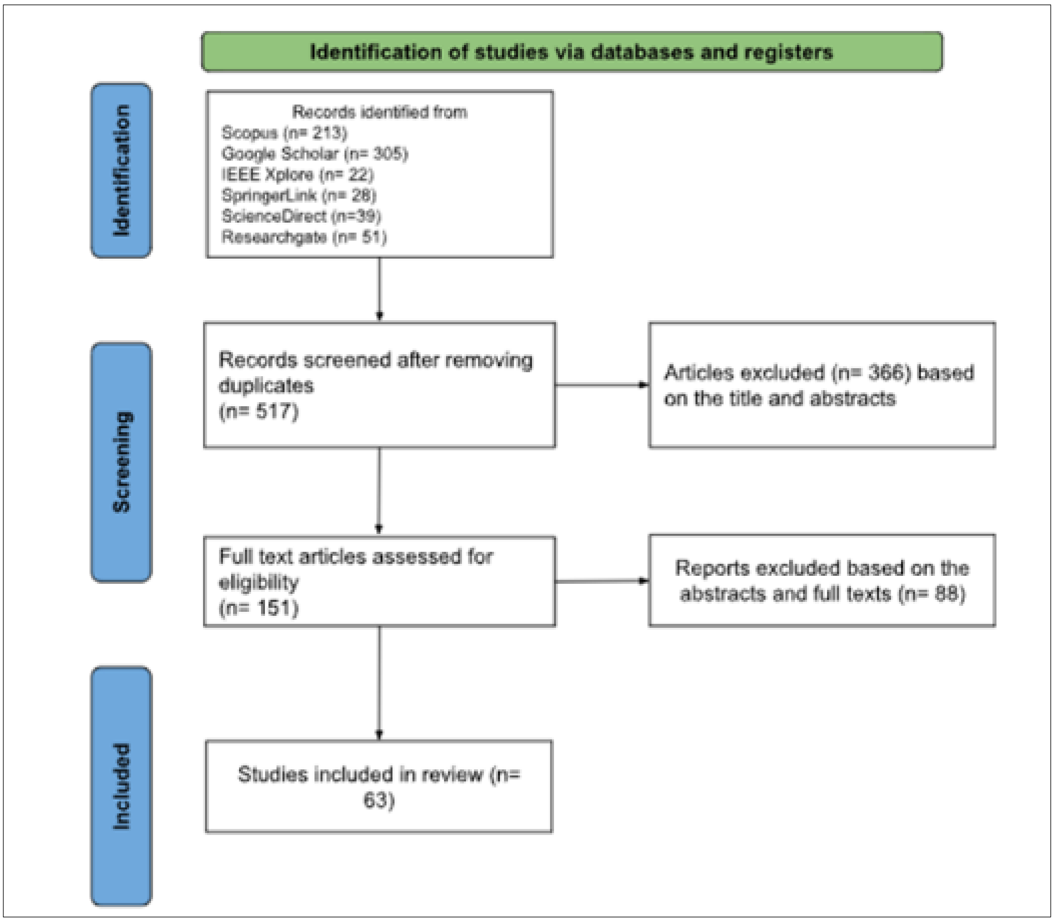

Figure 1 The screening process of the identified studies adapted from PRISMA.

3. Results

A total of 615 studies were identified. As shown from Figure 1, a total of 141 duplicates were identified and removed, leaving the screening phase with 517 publications. Based on titles and abstract reviews, 366 articles were excluded. After full-text analysis, 65 articles were finally included in the review.

As shown in Table 1, the number of studies covered by included articles varied from 10 [7] to 207 [13] articles. Approximately 35% of these articles were published between 2022–2023 and there's no study before 2019 as presented on Figure 2. About 29% (18) of the selected studies were published in 2021; studies published in 2019, 2020 and 2022 represented 9.5% (6), 25% (16) and 22% (14) of the total, respectively.

Table 1 Findings of the studies gathered

First Author	Year Published	Title	No. of Literature Used	Objectives (Focus)	Continent	Species	Findings
Gabriela Toninato de Paula [1]	2021	Stingless bees and microbial interactions	49	Medicine	South America	*Scaptotrigona depilis*	Stingless bees rely on their microbiota for fermenting food, producing crucial substances, and serving as essential food sources. The interaction between Zygosaccharomyces yeast and S. depilis emphasizes a vital symbiosis, with potential similar associations in other bee species.
Maggie Shanahan [2]	2021	Resin Use by Stingless Bees: A Review	125	Medicine	Global	*Meliponini*	Changes in beekeeping practices, such as massification and colony transport to monocrop fields, may limit stingless bees' access to diverse resin sources. This can impact nest construction, defense, and overall colony health. Recognizing the importance of resin is crucial for guiding conservation efforts to support stingless bees in maintaining their defenses and overall well-being.
Mohammad A. I. Al-Hatamleh [4]	2020	Antioxidant-Based Medicinal Properties of Stingless Bee Products: Recent Progress and Future Directions	158	Medicine	Global	*Meliponini*	Stingless bee products, with rich nutritional and medicinal properties, are understudied compared to other honey producers. This review explores their medicinal potential, suggesting redefining honey as a preventive agent due to its antioxidants and impact on disease progression signaling pathways.

Mary T. Fletcher [14]	2020	Stingless bee honey, a novel source of trehalulose: a biologically active disaccharide with health benefits	35	Medicine	Australia, Asia, and South America	*Tetragonula carbonaria* *Tetragonula hockingsi* *Geniotrigona thoracica* *Heterotrigona itama* *Tetragonisca angustula*	The UPLC-MS/MS analysis of honey from five stingless bee species revealed the presence of fructose, glucose, and a consistent disaccharide across all species. Despite initial suggestions of this disaccharide being maltose, the UPLC-MS/MS method demonstrated it was actually trehalulose, a glucose-fructose disaccharide. This discovery, confirmed through preparative HPLC, identifies trehalulose as a biologically active disaccharide previously unreported in stingless bee honey.
Milena Popova [15]	2019	Propolis of stingless bees: a phytochemist's guide through the jungle of tropical biodiversity	95	Medicine	Ameria, Asia, Australia	*Meliponini*	Chemical studies on Meliponini propolis reveal bioactive molecules, emphasizing the need for thorough characterization in pharmacological studies. Further research is needed to understand the significance of resin, bee species, and colony location, and to explore the commercial potential and medicinal properties of stingless bee propolis.
Fabíola Carina Biluca [16]	2020	Investigation of phenolic compounds, antioxidant and anti-inflammatory activities in stingless bee honey (Meliponinae)	45	Medicine	South America	*Scaptotrigona bicunctata* *Melipona marginata* *Tetragonisca angustula* *Trigona hypogea* *Melipona quadriasciata* *Tetragona clavipes*	The study found antioxidant potential in phenolic-rich stingless bee honey. Testing its anti-inflammatory effects on macrophages revealed reductions in inflammatory markers, with some samples showing broader impacts on specific pathways. The observed effects are likely associated with the honey's phenolic composition, but further research, including in vivo studies, is needed to explore additional factors influencing stingless bee honey's bioactivity.

Manap Trianto [17]	2020	Morphological characteristics and morphometrics of Stingless Bees (Hymenoptera: Meliponini) in Yogyakarta, Indonesia	50	Morphological characteristics	Asia	*Tetragonula laeviceps* *Tetragonula iridipennis* *Tetragonula biroi* *Tetragonula sapiens* *Tetragonula sarawakensis* *Lepidotrigona terminata* *Heterotrigona itama.*	The study shows different morphological characteristics of the different species of stingless bees and more. The study aims to help in the preservation of these bees.
Salma Malihah Mohammad [18]	2021	Stingless Bee-Collected Pollen (Bee Bread): Chemical and Microbiology Properties and Health Benefits	154	Chemical Profiling, Economical	America, Australia, Asia	*Meliponini*	This review highlights the market potential of stingless bee bee bread, rich in micronutrients and beneficial microbes, benefiting from the trend towards natural, health-focused products. The need for further research on its therapeutic values is emphasized, along with the importance of establishing international standards for increased commercial viability.
Farah Nadiah Rosli [19]	2020	Stingless Bee Honey: Evaluating Its Antibacterial Activity and Bacterial Diversity	48	Medicine	Asia	*H. fimbriata* *T. melanoleuca* *H. itama* *T. apicalis* *L. terminata* *G. thoracica* *T. binghami* *H. erythrogastra*	This study assessed honey from eight stingless bee species for antimicrobial properties, highlighting the effectiveness of Homotrigona fimbriata honey against four bacteria. The bacterial community analysis revealed diverse species, with Heterotrigona erythrogastra and Tetrigona melanoleuca showing high diversity. The findings suggest potential probiotic applications, especially focusing on Lactobacillus sp. from Homotrigona

							fimbriata honey for the food technology industry.
Milena Popova [20]	2021	A Preliminary Study of Chemical Profiles of Honey, Cerumen, and Propolis of the African Stingless Bee Meliponula ferruginea	64	Chemical Profiling	Africa	*Meliponula ferruginea*	The study revealed that resin collection from M. ferruginea results in diverse propolis and cerumen, while their honey is rich in trehalulose and organic acids, indicating potential biological activities. Further research is needed to explore these active substances, with potential economic benefits for rural farmers.
Salma Malihah Mohammad [21]	2020	Botanical Origin and Nutritional Values of Bee Bread of Stingless Bee (Heterotrigona itama) from Malaysia	74	Chemical Profiling, Economical	Asia	*Heterotrigona itama*	It was revealed that H. Tama bee bread is nutritionally rich in carbohydrates, proteins, minerals, and amino acids. Despite detecting acceptable levels of toxic heavy metals, values vary based on geographical locations. The findings suggest H. itama bee bread's potential as a functional food in the market, contributing to the development of quality standards for bee bread in Malaysia.
Enos Tangke Arung [22]	2021	Cytotoxicity effect of honey, bee pollen, and propolis from seven stingless bees in some cancer cell lines	33	Anti-Cancer	Global	*Homotrigona fimbriata, Heterotrigona itama* *Heterotrigona bakeri* *Tetragonula sarawakensis* *Tetragonula* *Testaceitarsis* *Tetragonula fuscobalteata*	Seven stingless bee species in East Kalimantan, Indonesia, including honey, bee pollen, and propolis, showed cytotoxic effects on cancer cell lines, with the H. fimbriata being the best. The study suggests the potential of H. fimbriata products as anticancer agents, but further research is required for validation.

						Tetragonula laeviceps.	
Fatin Aina Zulkhairi Amin [23]	2019	Probiotic Properties of Bacillus Strains Isolated from Stingless Bee (Heterotrigona itama) Honey Collected across Malaysia	61	Chemical Profiling, Medicine	Australia, Africa, Asia	*Heterotrigona itama.*	The stingless bee honey contains bacteria, such as Bacillus amyloliquefaciens HTI-19, with broad-spectrum antimicrobial properties, making it a good source for probiotic cultures. Two Bacillus strains from stingless bee honey also show possible probiotic characteristics, making it possible to be used by humans and animals. Further research may reveal new probiotic strains with specific health benefits.
Nornaimah Asem [24]	2019	Correlation between total phenolic and flavonoid contents with antioxidant activity of Malaysian stingless bee propolis extract	30	Medicine	Asia	*Tetrigona apicalis* *Heterotrigona itama* *Geniotrigona thoracica*	The study confirmed antioxidant properties in all Trigona sp. propolis samples, with G. thoracica exhibiting the highest activity. Propolis with more polyphenols showed stronger antioxidant effects, indicating its potential for therapeutic natural products. The study also suggests further research is needed to identify the key compounds responsible for propolis' antioxidant properties
Adriane Costa dos Santos [25]	2021	Phenolic composition and biological activities of stingless bee honey: An overview based on its aglycone and glycoside compounds	131	Chemical Profiling, Medicine	South America and Asia	*Melipona favosa* *Melipona subnitida* *Melipona scutellaris* *Melipona quadrifasciata* *Melipona mondury*	The review highlights Sidr bee honey's diverse phenolic compounds, over 80 in total, including aglycones. The study suggests investigating the impact of natural fermentation on phenolic composition, and recommends using methanol for extraction.

						Melipona bicolor *Melipona marginata* *Tetragona clavipes* *Tetragonisca angustula* *Trigona hypogea*	
Alemayehu Gela [26]	2020	Physico-chemical characteristics of honey produced by stingless bees (Meliponula beccarii) from West Showa zone of Oromia Region, Ethiopia	46	Chemical Profiling, Economical	Africa	*Meliponula beccarii*	The study shows that Ethiopian stingless bee honey shares physico-chemical characteristics with Apis mellifera honey, except for proline values. Its low pH and high acidity suggests that it may have medicinal value. A new management system is needed for Melipona beccarii due to variations in moisture and total acidity. Preservation of feral colonies is needed for sustainable honey production and income generation. Further studies are recommended.
Edineide Cristina A. Souza [27]	2020	Stingless bee honey (Hymenoptera, Apidae, Meliponini): a review of quality control, chemical profile, and biological potential	103	Medicine	America, Africa, Australia, Asia	*Hymenoptera, Apidae, Meliponini*	The review shows that there is a difference between stingless bee honey, Apis mellifera honey, and various stingless bee species. It also showed that specific regulations for assessing stingless bee honey quality are needed due to increasing demand. Further studies on conservation methods and chemical characterization are crucial for shelf life and product enhancement. This research gains urgency amid global environmental conservation concerns, offering a

							sustainable income opportunity for honey farmers.
Carla Menegatti [28]	2020	Meliponamycins: Antimicrobials from Stingless Bee-Associated Streptomyces sp.	33	Medicine	America, Europe	*Melipona scutellaris*	The study identifies two new cyclic hexadepsipeptides, meliponamycin A and meliponamycin B, from Streptomyces sp. ICBG1318 in M. scutellaris nurse bees using NMR, MS, and Marfey's method. It was revealed that both compounds show strong activity against the entomopathogen Paenibacillus larvae and human pathogens Staphylococcus aureus and Leishmania infantum.
Mohamad Syazwan Ngalimat [29]	2020	A Review on the Association of Bacteria with Stingless Bees	111	Medicine, Economical	Asia and South America	*Hetetrigona itama* *Scaptotrigona depilis* *Tetragonisca angustula* *Proplebeia dorninicana* *Malipona fasciata* *Trigona hypogea* *Melipona quadrifasciata* *Austroplebeia australis* *Tetragonula carbonaria* *Tetragonula hockingsii* *Tetragonula laeviceps*	The review underscores the crucial roles of bacteria in stingless bee products, including processing raw materials and protecting the nest. It suggests further investigation is needed to determine the bacteria's activity in bee products. Some bacteria show potential against pathogens, offering biocontrol and enzyme sources. Understanding the stingless bee-microbe relationship is vital for sustainable meliponiculture, urging research on microbial diversity in healthy colonies for insights into bee health and productivity.

						Tetragonula fuscobalteata	
Francisco Assis Nascimento Pereira [30]	2021	Use of Stingless Bee Propolis and Geopropolis against Cancer—A Literature Review of Preclinical Studies	66	Anti-Cancer	America, Africa, Asia, Australia	*Plebeia, Trigona* *Melipona, Scaptotrigona* *Trigonisca*	Stingless bee propolis and geopropolis extracts show diverse chemical compositions with a possibility of antineoplastic effects against tumor cell lines. Further studies and clinical trials are needed to confirm the safety and efficacy in treating cancer.
Jaqueline Ferreira Campos [31]	2021	Stingless Bee Propolis: New Insights for Anticancer Drugs	149	Anti-Cancer	Global	*Melipona* *Plebeia* *Trigona* *Scaptotrigona* *Trigonisca* *Tetragonisca*	Research on natural products such as propolis from stingless bees is critical for identifying new cancer therapies that would minimize side effects and enhance treatment effectiveness. The diverse stingless bee species worldwide present significant bioprospecting possibilities for developing anti-cancer drugs. Natural products, such as propolis, offer novel structures for effective agents against diseases, including cancer. The chemical diversity and cell death mechanisms induced by stingless bee propolis show promising potential for new antitumor drugs, further preclinical trials and research is needed.
Ali, H. [32]	2020	In vitro anti-diabetic activity of stingless bee honey from different botanical origins	26	Medicine	Asia	*Heterotrigona itama*	Stingless bee honey shows potential as a source of bioactive compounds. Different honey types show α-amylase and α-glucosidase inhibitory abilities, showing possible benefits for managing diabetes. Also, coconut-origin honey exhibits high α-glucosidase inhibition due to rich phenolic and flavonoid content. Overall, stingless bee honey is recommended for nutraceutical and pharmaceutical

							applications, the need for further research is recommended.
Hosea O. Mokaya [33]	2021	Characterization of honeys produced by sympatric species of Afrotropical stingless bees (Hymenoptera, Meliponini)	40	Chemical Profiling	Africa	*Liotrigona* *Meliponula (Meliponula) bocandei* *Meliponula (Axestotrigona) ferruginea* *Meliponula (Meliplebeia) lendliana* *Meliponula (Axestotrigona) togoensis* *Plebeina armata*	This study shows the significant impact of bee species on the composition of stingless bee honey (SBH). While harvesting methods showed no significant difference, the study recommends "punching holes" to maintain honey quality. Most samples, especially Liotrigona sp., were rich in phytochemicals with a significant radical scavenging activity. However, certain SBH samples did not meet standards for specific attributes, emphasizing the need for separate standards for SBH. Further study is recommended.
Sharifah Nur Amalina Syed Salleh [34]	2021	Analysis of bioactive compounds and chemical composition of Malaysian stingless bee propolis water extracts	48	Chemical Profiling	Asia	*Tetrigona apicalis* *Tetrigona binghami* *Heterotrigona fimbriata.*	The study assessed bioactive compound concentrations, including total lipid, vitamin C, carbohydrate, terpenoid, alkaloid, flavonoid, phenolic, and amino acid, in Malaysian stingless bee propolis water extracts from H. fimbriata, T. apicalis, and T. binghami. Additionally, GC–MS analysis identified major compound groups, showing no significant differences between samples. Further research on the biochemical compounds and applications of stingless bee propolis is recommended.
Wen-Jie Ng [35]	2020	The Antibacterial Potential of Honeydew Honey Produced by Stingless Bee	47	Medicine	Asia	*Heterotrigona itama*	Stingless bee honeydew honey demonstrated potent antibacterial properties, including both inhibitory and bactericidal effects. The study highlighted

		(Heterotrigona itama) against Antibiotic Resistant Bacteria				*Geniotrigona thoracica*	a synergistic effect when combining this honey with antibiotics against antibiotic-resistant bacteria. The findings suggest the potential of honeydew honey produced by the stingless bee H. itama as an effective antibacterial agent in healthcare.
Syafrizal [36]	2020	Diversity and honey properties of stingless bees from meliponiculture in East and North Kalimantan, Indonesia	22	Medicine	Asia	*Heterotrigona itama* *Tetragonula laeviceps*	The study found 12 stingless bee species, mainly cultivating Heterotrigona itama and Tetragonula laeviceps, except in Balikpapan. Phytochemical analysis done in the study revealed various compounds, and Tetragonula sarawakensis honey exhibited the highest radical scavenging activity. The study suggests that stingless bee honey contains antioxidants with potential health benefits for humans.
Sharifah Nur Amalina Syed Salleh [37]	2021	Determination of Total Phenolics, Flavonoids, and Antioxidant Activity and GC-MS Analysis of Malaysian Stingless Bee Propolis Water Extracts	42	Chemical Profiling	Asia	*Tetrigona apicalis* *Tetrigona binghami, Homotrigona fimbriata.*	Propolis from Malaysian stingless bee species T. apicalis, T. binghami, and H. fimbriata shows significant possibilities for pharmaceutical and health applications. The concentration of Total Phenolic Content (TPC) follows the order: H. fimbriata > T. binghami > T. apicalis, while Total Flavonoid Content (TFC) and DPPH scavenging activity rank as H. fimbriata > T. apicalis > T. binghami. The study suggests the need for further research to enhance the antioxidant and flavonoid production in nonalcoholic propolis extracts for better utilization in the food and medical industries.
Fatin Haniza Zakaria [13]	2022	Pathophysiology of Depression: Stingless	207	Medicine	Asia	*Tetrigona apicalis*	The review suggests that stingless bee honey (SBH) may have prophylactic effects against depression. It highlights

		Bee Honey Promising as an Antidepressant				*Tetrigona binghami* *Homotrigona fimbriata.*	SBH's potential in controlling depression symptoms through its amino acid (phenylalanine), antioxidant, and anti-inflammatory properties, aligning with various hypotheses. The review calls for further studies to identify specific bioactive compounds in SBH and explore additional pathways contributing to its antidepressant effects.
Flavia C. Lavinas [38]	2018	Brazilian stingless bee propolis and geopropolis: promising sources of biologically active compounds	79	Medicine	South America	*Nannotrigona testaceicornis* *Tetragonisca* *Angustula* *Scaptotrigona* *Melipona rufiventris* *Melipona quadrifasciata.*	The review highlights the biological potential of Brazilian native stingless bee propolis, showing its antioxidant and antimicrobial properties. Propolis from various species shares a common chemical profile, mainly rich in terpenoids and flavonoids. Unique constituents are found in propolis from Frieseomelitta longipes and Scaptotrigona bipunctata.Silico analysis suggests, despite debates on toxicity, the safety of most propolis substances for consumption.
Vítor Moreira Rocha [39]	2023	Stingless bee propolis: composition, biological activities and its applications in the food industry	107	Chemical Profiling, Medicine	South America, Asia, Africa	*Tetragonula carbonaria* *Tetragonisca febrigi* *Plebeia droryana* *Trigona minor* *Trigona* *Scaptotrigona jujuyensis* *Tetragonula af. Biroi*	Despite the well-studied chemical profile for Stingless bee propolis, the study calls for standard research parameters that are needed for consistency. Phenolic compounds revealed in this study are particularly noteworthy for their preventive properties against diseases, microorganisms, and free radicals. Propolis, beyond its functional food potential, shows promise as a natural substitute for chemical additives, extending the shelf life of products and serving as a sanitizer in the food industry.

						Heterotrigona itama *Lisotrigona furva* *Meliponula ferruginea*	
M A A Che Ali [5]	2021	A Review on the Stingless Beehive Conditions and Parameters Monitoring using IoT and Machine Learning	25	IoT System	Asia	*Heterotrigona Itama*	The article explores using IoT and machine learning to optimize conditions in stingless beehives for increased honey production. This approach, part of utilizing Industrial Revolution 4.0, involves real-time data to determine optimal hive conditions based on beekeeper actions, potentially leading to a higher number of stingless bee breeders.
Pedro A. B.Gomes [6]	2020	An Amazon stingless bee foraging activity predicted using recurrent artifcial neural networks and attribute selection	40	Neural Networks	America	*Melipona fasciculata*	The study employs Recurrent Neural Networks (RNN) to predict bee activity levels, finding that GRU performs better than LSTM. Using larger input windows, particularly the preceding 24 hours, improves accuracy significantly. The research assesses the importance of environmental variables (solar irradiance, temperature, and barometric pressure) for predicting bee activity when RFID systems are unavailable. Utilizing these weather variables alone, with optimized window sizes, yields an average RMSE error of 0.229, which improves to 0.212 with Permutation Feature Importance and correlation analysis. The study aims to enhance understanding of bee behavior, benefiting the environment and agriculture, with future work planned on factors like

							parasites, pesticides, weather changes, monoculture farming, and beehive management.
David Masereti Makori [40]	2022	The use of multisource spatial data for determining the proliferation of stingless bees in Kenya	100	EN Model	Africa	*meliponine*	This study employed machine learning to predict the spatial distribution of stingless bees in Kenya, emphasizing careful variable selection. The ensembled models highlighted key factors like bioclimatic data and vegetation phenology. Future projections (2055) indicated a decline in suitable habitats due to climate change, providing insights for beekeepers, farmers, and conservationists.
Akililu Mulatu [41]	2021	Adoption of Modern Hive Beekeeping Technology: The Case of Kacha-Birra Woreda, Kembata Tembaro Zone, Southern Ethiopia	76	Technology Adoption	Africa	*Heterotrigona Itama*	The adoption of modern hive beekeeping faces barriers due to personal, economic, and institutional factors. The study shows low adoption rates influenced by education, land size, access to resources, and market conditions. Limited finances lead many farmers to use modern hive beekeeping as a supplementary income source, highlighting its role in poverty alleviation.
Muhammad Ammar Asyraf Che Ali [42]	2023	Development of Artificial Stingless Bee Hive Monitoring using IoT System on Developing Colony	21	IoT System	Asia	*Heterotrigona Itama*	The project ensured sensor validation to meet standard accuracy and precision requirements before integrating an artificial hive into an Internet of Things monitoring system. Long-term monitoring helps predict honey production, while analysis reveals a healthy colony. However, the high temperature reading of 39.4 degrees Celsius poses a risk, suggesting the need for future hives with heat-resistant

							materials and heat transfer mechanisms to prevent Colony Collapse Disorder.
Rodrigo Cupertino Bernardes [43]	2022	Artificial Intelligence-Aided Meta-Analysis of Toxicological Assessment of Agrochemicals in Bees	55	Machine Learning	Global	*Meliponini*	Machine learning is utilized to efficiently assess a large volume of articles on agrochemical toxicology for insect pollinators. The review revealed a predominant focus on Hymenoptera, especially Apidae bees, with neonicotinoid insecticides being the most studied in laboratory settings. The findings provide valuable insights for guiding future research in this area.
Wan-Noorshahida Mohd-Isa [44]	2019	Image Segmentation of Meliponine Bee using Faster R-CNN	16	Neural Network	Asia	*Meliponine*	The paper presents a deep learning framework, Faster R-CNN, for Meliponine image segmentation, achieving a promising accuracy rate of almost 74%. Future work suggestions include implementing pre-processing tasks like enhancing color contrast to further improve the system's performance for developing a visual-based expert system in this field.
Mustafa Man [45]	2019	An Intelligent Stingless Bee System with Embedded IOT Technology	18	IoT System	Asia	*Meliponini*	The study utilized a system for Nature n Trigona Garden that allows remote monitoring of over a hundred beehives using GPS, temperature, and humidity sensors, saving time and money. It enhances safety and efficiency through user registration. Future improvements include internet access through SIM cards for continuous location tracking and waterproof cases for device durability.

Mohamad Taib Miskon [46]	2022	A Lora-based Testbed Development for Stingless Bee Monitoring System	27	Testbed Construction	Didn't Specify	*Didn't Specify*	A basic testbed for monitoring stingless bee hives was constructed and tested in this study, revealing areas for improvement. The weight sensor proved ineffective in severe winds, suggesting a need for reconsideration. A higher-grade smoke sensor and a waterproof temperature and humidity sensor are recommended due to weather conditions. Additionally, considering an accelerometer for measuring vibration caused by external factors is suggested.
Noor Hafizah Khairul Anuar [47]	2019	IoT Platform for Precision Stingless Bee Farming	10	IoT System	Asia	*Didn't Specify*	This paper introduces a low-energy platform for monitoring stingless bee foraging, hive temperature, and humidity, operating for 12 days on a single charge. It provides professional monitoring functions, integrates with an IoT platform, and aids beekeepers in estimating honey and brood cell production. Future recommendations include yearly temperature and humidity data analysis for predicting hive health patterns using big data and artificial intelligence, along with integrating stingless bee counter sensors at hive entrances for enhanced monitoring of bee activities.
Siti Nurhidayah Sharin [48]	2023	Impact of Harvesting Seasons on Physicochemical Properties and Volatile Compound Profiles of Malaysian Stingless Bee Honey Analyzed using Chemometrics and	40	Chemical Profiling	Asia	*Heterotrigona bakeri* *Geniotrigona thoracica* *Tetrigona binghami*	The research identified potential markers, including seventeen volatile compounds, for effectively distinguishing stingless bee honey based on harvesting seasons. These markers, obtained through individual and cumulative data analysis, can serve as valuable references for discerning honey from different bee species between rainy and dry seasons.

		Support Vector Machine					
Patricia Vit [49]	2021	Metabolomics applications in bee science	28	Meta-analysis, Chemical Profiling	America	*Apis mellifera* *Austroplebeia australis* *Bombus terrestris* *Heterotrigona itama* *Meliponula ferruginea* *Tetragonula carbonaria* *Tetragonula hockingsi*	This study employed a robust meta-analysis to identify a core set of genes associated with early-stage social evolution in Hymenoptera. These genes form a genetic toolkit, foundational for the emergence of reproductive division of labor in eusociality. The study suggests adopting similar approaches in future research to explore the genetic toolkit's role in different forms of sociality and superorganismality.
Endra Joelianto [50]	2020	Stingless bee algorithm for numerical optimization problems	75	Machine Learning, Algorithms, Preservation	Asia	*No specific species*	The paper introduced the Stingless Bee Algorithm (SBA), inspired by stingless bee foraging behaviors, demonstrating comparable performance to the Artificial Bee Colony (ABC) in solving numerical problems. SBA outperformed ABC in convergence speed, while ABC excelled in specific criteria. The SBA's efficiency and effectiveness make it a promising algorithm for numerical optimization. Future research aims to enhance SBA by exploring additional stingless bee foraging behaviors, potentially unifying foraging behaviors of honey bees and stingless bees into a powerful algorithm or allowing each algorithm to grow independently based on bee nature.

Ayalew Assefaa [51]	2022	Ecological niche modeling for stingless bees (genus Melipona) in Waghemira and North Wollo zones of Amhara Regional State, Ethiopia	19	Niche Modeling, Preservation	Africa	*Hymenoptera Meliponini*	This study in Ethiopia identifies highly suitable territories for stingless bees in districts such as Sekota and Dehana in Wag and Lalibela in Lasta. Unsuitability was observed in lowland districts like Abergelle, Ziquala, and Sahala Seyemnt. Key contributing variables include water vapor pressure, precipitation seasonality, elevation, temperature annual range, and wind speed. The findings are crucial for stingless bee collection, domestication, and commercialization in the region, suggesting the need for further research at a national or sub-regional level with more occurrence data and genus Melipona characterization.
Tanvir Bhuiyan [52]	2022	Artificial intelligence versus natural selection: Using computer vision techniques to classify bees and bee mimics	55	Machine Learning	America	*Meliponini*	This study utilizes machine learning techniques to progress from 'explainable AI' to 'explainable mimicry,' decoupling color from pattern and identifying diagnostic anatomical regions. The approach offers a novel way to quantify mimetic fidelity, potentially impacting conservation efforts for endangered species. The study envisions foundational insights and applications with the expansion of datasets and advances in computer vision.
Wyatt A. Shell [53]	2022	Comparative metagenomics reveals expanded insights into intra- and interspecific variation among wild bee microbiomes	113	Machine Learning, Medicine	America, Australia	*Meliponini Tetragonula fuscobalteata*	This study presents metagenomic data from three global carpenter bee species, establishing the first carpenter bee core microbiome. Machine learning and network analyses reveal unique metagenomes influenced by local environmental features, with evidence of plant pathogens observed in honey bees.

							The comprehensive analysis shows an inverse relationship between microbiome diversity and host species' social complexity. This research contributes essential hologenomic data on wild bees, offering insights into the biology and health of crucial pollinators.
Prashanta Kumar Mitra [54]	2023	Low-cost rapid workflow for honey adulteration detection by UV-Vis spectroscopy in combination with Factorial designs, Response surface models and Clustering	46	Machine Learning, Spectroscopy	Asia	*Not specified*	The cluster analyses done in this study successfully differentiated adulterated and unadulterated honeys, showcasing the method's effectiveness. Although currently representing qualitative data, the method's strength lies in its quick generation of quantitative data with minimal resources. Repeating the workflow with different samples can enhance understanding and lead to improved factorial designs for detecting honey adulteration. The developed factorial design for clustering absorption spectra has the potential to provide precise results and interpretations.
Muna E. Raypah [55]	2022	Identification of Stingless Bee Honey Adulteration Using Visible-Near Infrared Spectroscopy Combined with Aquaphotomics	75	Machine Learning, Spectroscopy	Asia	*Not Specified*	The study demonstrates the effectiveness of Vis-NIR spectroscopy (400-1100 nm) for identifying adulterated SBH based on spectral alterations related to color and water properties. The aquaphotomics approach at short-wavelength NIR (800-1100 nm) successfully identified SBH adulteration levels, suggesting a potential method for sensitive and portable detection.
Azmi, M.F.I. [56]	2021	Adulterated stingless bee honey identification using	43	Machine Learning, Spectroscopy	Asia	*Not Specified*	The study found that pure stingless bee honey had the highest transmittance rate at 787.677 nm and superior SSC and RI

		VIS-NIR spectroscopy technique					values compared to adulterated samples. Using PCA-LDA, PCA-QDA, and PCA-SVM for classification, all methods achieved 99.33% accuracy based on VIS-NIR properties. The study identified 34 significant wavelengths for discriminating treatments. Future work aims to gather more accurate data for rapid prediction of stingless bee honey adulteration.
Diding Suhandy [57]	2023	Non-Targeted Detection and Quantification of Food Adulteration of High-Quality Stingless Bee Honey (SBH) via a Portable LED-Based Fluorescence Spectroscopy	86	Machine Learning, Spectroscopy	Asia	*Heterotrigona itama*	The study utilized portable LED-based fluorescence spectroscopy to detect HFCS-55 adulteration in stingless bee honey (SBH). It accurately discriminated between pure and adulterated SBH samples with 100% accuracy, identifying crucial wavelengths. The technology offers field-friendly, small-volume SBH authentication. Further diverse sample studies are recommended for result generalization. Integration with smartphones and the internet could enhance real-time food traceability.
Wei Chean Chuah [58]	2023	Antioxidants Discovery for Differentiation of Monofloral Stingless Bee Honeys Using Ambient Mass Spectrometry and Metabolomics Approaches	48	Chemical Profiling, Medicine	Asia	*Heterotrigona itama*	The study investigates the antioxidant properties of stingless bee honeys (SBHs) based on botanical sources. Acacia honey stands out for its superior qualities. Using untargeted metabolomics, the research distinguishes SBHs by their botanical origins, providing a reliable tool for authenticity and traceability. Further validation of specific compounds is essential for quality control, boosting consumer confidence in locally produced honeys.

Khairunnisa Embi [59]	2022	Discrimination of Adulterated Stingless Bee Honey with Different Types of Local Adulterants by Spectroscopy using Chemometric Techniques	11	Machine Learning, Spectroscopy	Asia	*Heterotrigona itama*	This study effectively differentiated natural stingless bee honey (H. itama) from adulterated honey using physical properties and ATR-FTIR with chemometrics on 108 samples. PCA and LDA showed clear grouping, achieving the goal of creating a model for discerning adulterated stingless bee honey with various local adulterants.
Mohd Azri Abd Jalil [60]	2022	Perceptions on The Therapeutic Effects of Stingless Bee Honey and its Potential Value in Generating Economy among B40 Community of Kampung Bukit Kuin, Kuantan	24	Economical	Asia	*Not Specified*	Stingless bee honey in Malaysia is recognized for its health benefits, nutritional value, and traditional uses. As its market grows, particularly benefiting small farmers and the B40 community in Kampung Bukit Kuin, Kuantan, government support is recommended to further promote and sustain this agricultural initiative.
Asaduz Zaman [61]	2023	A framework for better sensor-based beehive health monitoring	133	Preservation	Australia	*Meliponini*	This study presents the OIP framework for beehive monitoring—Operational, Investigative, Predictive. Operational monitoring automates processes, Investigative monitoring has grown since 2003, and Predictive monitoring, emerging in 2008, shows promise. Disparities in monitoring across bee species and regions are highlighted. Lower-income countries can leverage Operational and Investigative knowledge for Predictive monitoring, emphasizing the potential benefits in regions facing food security challenges. The study underscores the need for a comprehensive global approach to bee health and environmental concerns.

Fernanda S. Luccas [62]	2022	Optimization of sample preparation of Brazilian honeys for TQ-ICP-MS analysis	35	Machine Learning	South America	*Tetragonisca angustula (Jataí)* *Apis mellifera sp (Apis)*	This study optimized honey digestion with 3 mL HNO3 and 1 mL H2O2, ensuring lower detection limits and recoveries between 80-120% for key elements. Machine learning (MLP, RF, SVM) achieved 99% accuracy in classifying honeys by entomological origin. The study recommends these approaches for authenticating and certifying Brazilian honey.
Nellysha Namela Muhammad Abdul Kadar [63]	2022	Comparable Benefits of Stingless Bee Honey and Caffeic Acid in Mitigating the Negative Effects of Metabolic Syndrome on the Brain	69	Medicine	Asia	*Heterotrigona itama*	This study found that a high-carbohydrate, high-fat (HCHF) diet increased blood pressure, blood sugar, and triglyceride levels in rats with metabolic syndrome (MetS). MetS-induced rats showed elevated brain TNF-α and reduced brain BDNF levels. Supplementation with stingless bee honey (SBH) from H. itama and catalase (CA) mitigated some effects, reversing hyperglycemia and hypertension, reducing brain TNF-α, and increasing brain BDNF levels.
W Halwany [64]	2020	A simple reducing water content technique for stingless bee honey (Heterotrigona itama) in South Kalimantan	20	Economical, Preservation	Asia	*Heterotrigona itama*	This study formulated a modified Simple Honey Water Content Reducer Device (SHWCRD) reduces the water content of stingless bee honey (Heterotrigona itama) to 6% in 3 hours at 40°C, enhancing its storage life for farmers.
H A Rosli [65]	2022	Iot Based Monitoring System for Stingless Bees Colony in Iium	11		Asia	*Not Specified*	The project successfully monitored beehive parameters using an ESP8266 wifi module for IoT implementation. It allows remote observation of stingless bee behavior and provides real-time alerts. To enhance the weighing system,

							using four load cells in a Wheatstone bridge configuration is recommended. Considering a GSM module for continuous internet connection is also proposed, especially in areas with limited wifi coverage.
D Suhandy [66]	2022	Rapid authentication of stingless bees (Heterotrigona itama) honey by UV spectroscopy and hierarchical cluster analysis	20	Spectroscopy	Asia	*Heterotrigona itama*	The study used UV spectroscopy and hierarchical cluster analysis to differentiate between stingless and non-stingless bee honey samples. Results from principal component analysis and hierarchical cluster analysis confirmed successful classification. The study suggests that UV spectroscopy and HCA could soon be employed for authenticating stingless bee honey.
Noor Hafizah Khairul Anuar [7]	2021	Embedded Wireless Stingless Beehive Monitoring And Data Management System	19	IoT	Asia	*Heterotrigona Itama*	The study presented EMAS, an embedded electronic system for monitoring stingless bee hives through IoT and Android apps. It tracks temperature, humidity, honey container weight, bee count, and calculates dew point for air moisture. The system aids farmers in monitoring and managing farm activity, with plans for widespread installation and long-term data observation to enhance performance.
Rodrigo Cupertino Bernardes [67]	2021	Ethoflow: Computer Vision and Artificial Intelligence-Based Software for Automatic Behavior Analysis	52	AI	Did not specify	*Not Specified*	The study introduces Ethoflow, an AI-based software for computer vision applications. Ethoflow is effective for diverse tasks such as multivariate kinematic evaluations, behavioral assessments, and tracking individuals in groups. It has been successfully applied to detect differences in bee species and

							pesticide stress. Ethoflow's potential extends to behavioral monitoring in precision livestock farming, and regular updates are planned to enhance its capabilities. Overall, Ethoflow is a valuable tool for technical and scientific applications in biology and related fields.

Table 1 depicts the 63 studies reviewed in this systematic review. Details such as first author, year of publication, title, number of literatures used, and focus of the study were collected. As mentioned in methodology, continents of where the study was conducted, species of stingless bees used, and a short summary of the findings of the study were also compiled and collected.

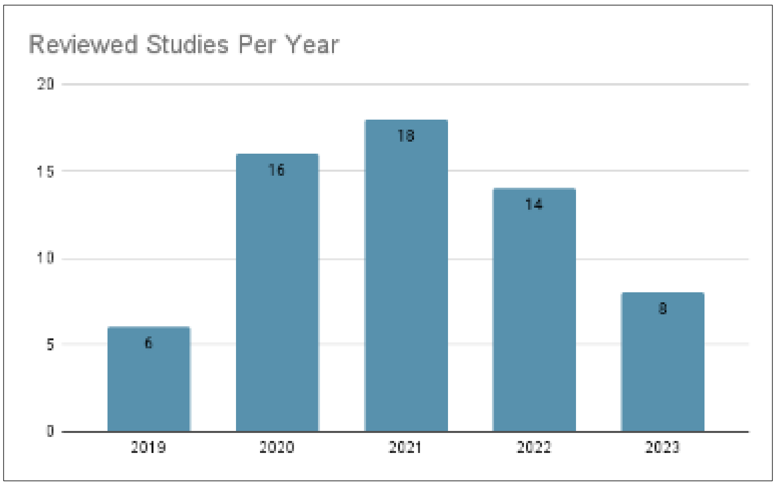

Figure 2 Number of reviewed studies per year

Figure 2 shows the number of reviewed studies along with the year of its publication. As of 2023 the research studies that were gathered regarding stingless bee products and machine learning showed that there were more studies published in the year 2021 than any other year. The studies gathered in the year 2021 have a total of 18 studies followed by the year 2020 with 16 and the year 2022 with 14 studies published.

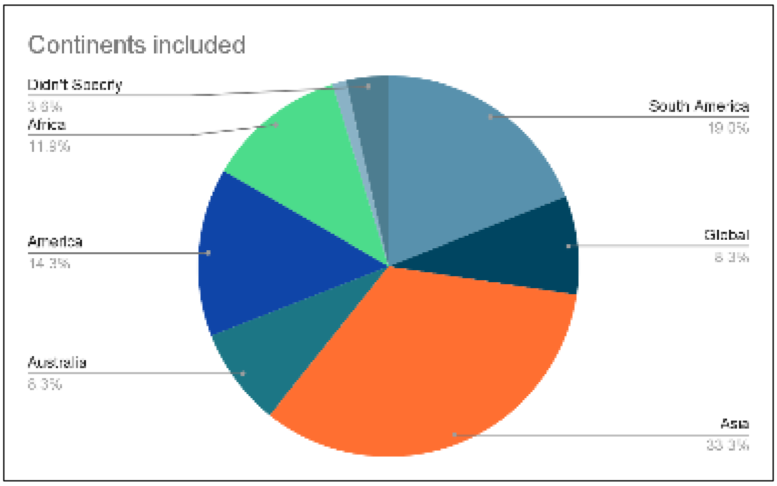

Figure 3 Continents of where the studies were conducted

Figure 3 reflects the continents of where the studies used in this systematic review were conducted. The division ranges from 8.3% (Australia) to 33.3% (Asia). A total of 8.3% of the studies were conducted globally which are mostly systematic reviews conducted to review stingless bees from all over the world. A small number of these studies (3.6%) did not specify the continent to where their methods were conducted. Studies published from Africa, America, South America represented 11.9% (10), 14.3% (12), 19% (16) respectively. This indicates that from the span of 5 years, a large number of studies focusing on the advancements involving stingless bees were all conducted from Asia.

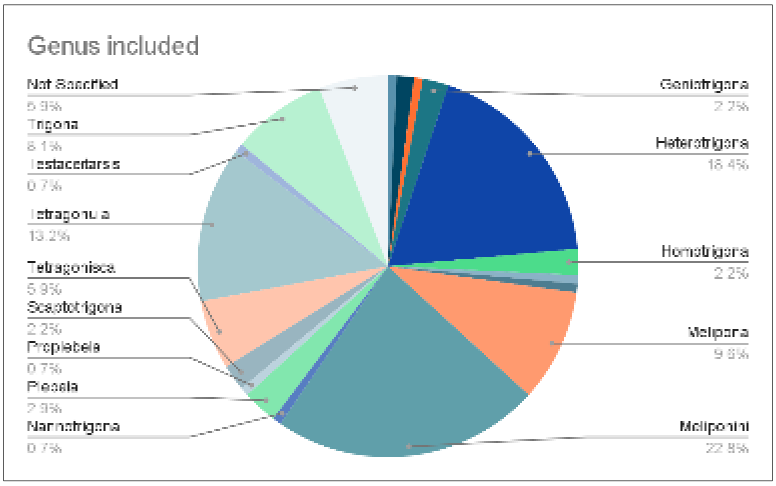

Figure 4 Genuses of stingless bees used in the studies

Figure 4 shows the genuses of stingless bees used in the studies gathered in this systematic review. The Genus used ranges from at least 0.7% (Proplebeia) to at most 22.8% (Meliponini). A total of 5.9% of the studies did not specify the genus of the stingless bees they used in their methodology. Figure 4 indicates that studies conducted focusing on the advancements involving stingless bees were mostly conducted in the genus of Meliponini. It is also notable that a number of studies involving Heterotrigona, Tetragonula, Melipona, Trigona, and Tetragonisca were represented at 18.4%, 13.2%, 9.6%, 8.1%, and 5.9% respectively.

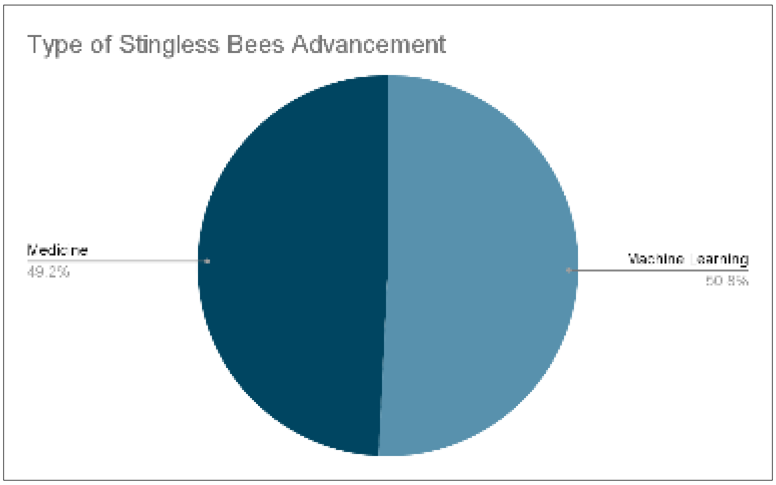

Figure 5 Type of Stingless Bees Advancement

Figure 5 represents the division of the types of stingless bees advancement present from the studies included in this systematic review. A total of 50.8% or 32 studies focused on the application of machine learning in Stingless bee products while a total of 49.2% all dedicated to the medicinal advancements and possibilities of stingless bees.

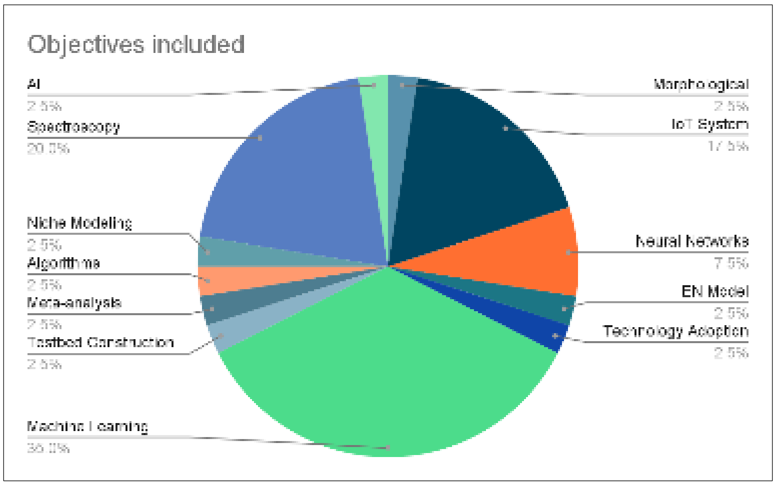

Figure 6 Specified Machine Learning Advancements

Figure 6 illustrates the specified machine learning advancements present from studies gathered in this systematic review. It is notable that a majority of the studies (35%) included were conducted with the use of machine learning, generally. It is also noteworthy that large parts of the total used Spectroscopy (20%), IoT systems (17.5%), and Neural Networks (7.5%).

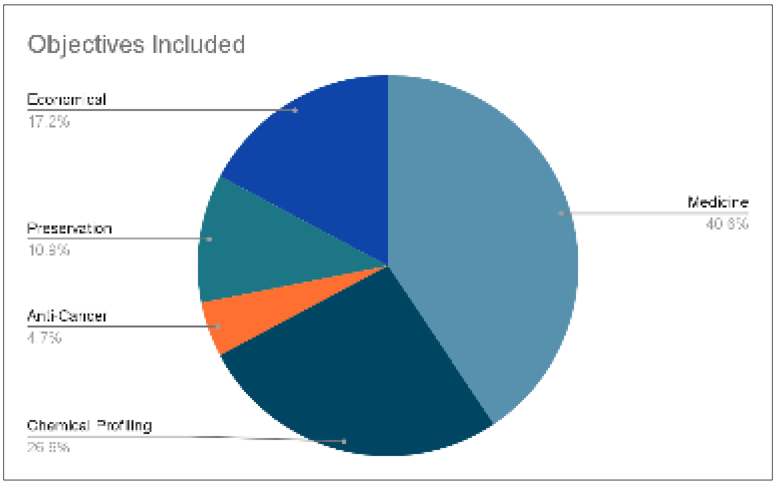

Figure 7 Stingless bee products and their possible applications

Figure 7 shows the different possible applications taken into account in this study. It is notable that the majority of the studies include advancement in the field of medicine (40.6%) by studying the different effects of bee products and what help it can provide in healing the human body. The different applications include: Chemical profiling, where researchers breakdown the stingless bee products to a molecular level and understand its adverse effects; Economical, studies which include commercializing stingless bee products; Preservation, where researchers study the different behaviors of different species of stingless bee in order to prevent the reduction of their population and; Anti-Cancer, where researchers study how stingless bee products can help cancer patients.

4. Discussion

In summary, the systematic review of 63 selected studies from a pool of 615 reveals a recent surge in research on stingless bee products and machine learning. The majority of studies were concentrated in Asia, with a notable absence of research before 2019. Meliponini emerged as the primary genus of interest. The study's focus was divided between machine learning applications (50.8%) and medicinal advancements (49.2%). Machine learning techniques, including Spectroscopy, IoT systems, and Neural Networks, were prominently featured. Noteworthy applications included medicinal advancements (40.6%), chemical profiling, economic considerations, preservation strategies, and anti-cancer research.

5. Conclusion

In conclusion, the systematic review underscores the growing interest and diverse applications of stingless bee products, especially when coupled with machine learning techniques. The concentration of studies in Asia, the dominance of Meliponini as a studied genus, and the balanced attention to medicinal and machine learning aspects collectively contribute to a comprehensive understanding of the advancements in this field. The results provide valuable insights for researchers, policymakers, and stakeholders interested in the sustainable utilization of stingless bee products and the integration of machine learning technologies in this domain.

Given the evolving landscape of stingless bee product research and its intersection with machine learning, further exploration and collaboration across disciplines are recommended. Researchers are encouraged to focus on global perspectives, expanding beyond regional concentrations, and to explore applications beyond medicinal advancements. Additionally, fostering interdisciplinary partnerships could lead to innovative approaches, ultimately contributing to the sustainable utilization of stingless bee products and the advancement of machine learning techniques in various fields and not just medicinal and agricultural.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no relevant affiliations or financial ties with any organization or entity that could pose a financial interest or conflict related to the subject matter or materials discussed in the manuscript. This includes aspects such as employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, and royalties.

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Authors contribution

Name of Researcher	Contribution
Joseph Louis Michael C. Ramos	Reviewing of studies and writing of paper
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Edwin R. Arboleda	Proofreading and paper adviser

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